It is therefore clear that the large alteration produced by the acid in the value of the ratio of the final to the initial rotation in the experiments on the hydrolysis of cane sugar can be completely and satisfactorily explained by the changes produced by the acid in the rotatory powers of the three sugars involved.

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# *The Decrease in Velocity of α-Particles in Passing through Matter.*

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It is becoming recognised that one of the most fruitful sources of information as to the internal structure of atoms is provided by the phenomena attending the passage of swift electrified particles through them. In particular from a consideration of the scattering of $\alpha$-particles it has been found that the atom consists essentially of a very concentrated charge at the centre of the atom[*] surrounded by electricity of the opposite sign, probably electrons, distributed throughout the remainder of the atom. Further, Darwin[†] and Bohr[‡] have attempted to obtain information as to the number and distribution of electrons in the atom by a consideration of the absorption or loss of velocity of the $\alpha$-particles in passing through matter. The only data for this purpose so far obtainable are provided by the velocity curves, or relations between velocity and thickness of matter traversed, in aluminium as determined by Rutherford,[§] and in mica as determined by Geiger.[||] It seemed, therefore, of interest to make a more complete investigation of the velocity curves in various substances, more particularly as the earlier observations are subject to slight errors due to the assumption that equal thicknesses of matter have the same air equivalent at different parts of the range of $\alpha$-particles.

In the present experiments the velocity curves in gold, copper, aluminium, mica and air have been determined, using as source the $\alpha$-particles of radium C as in the experiments of Rutherford and of Geiger. The velocities of the $\alpha$-particles before and after passing through sheets of matter of various thicknesses were measured by the deflection of the $\alpha$-particles in a known magnetic field. The apparatus used is shown in fig. 1. It consists essentially of a source of radiation D, a series of absorption foils T, a slit L, to form a pencil of the $\alpha$-particles, and a zinc sulphide screen M on which the position of the pencil could be observed, the whole being enclosed in an evacuated chamber C between the poles of a large electromagnet.

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[*] E. Rutherford, 'Phil. Mag.,' 1911, vol. 21, p. 669.

[†] C. G. Darwin, 'Phil. Mag.,' 1912, vol. 23, p. 907.

[‡] N. Bohr, 'Phil. Mag.,' 1913, vol. 25, p. 10.

[§] E. Rutherford, 'Phil. Mag.,' 1906, vol. 12, p. 138.

[||] Geiger, 'Roy. Soc. Proc.,' 1910, A, vol. 83, p. 505.

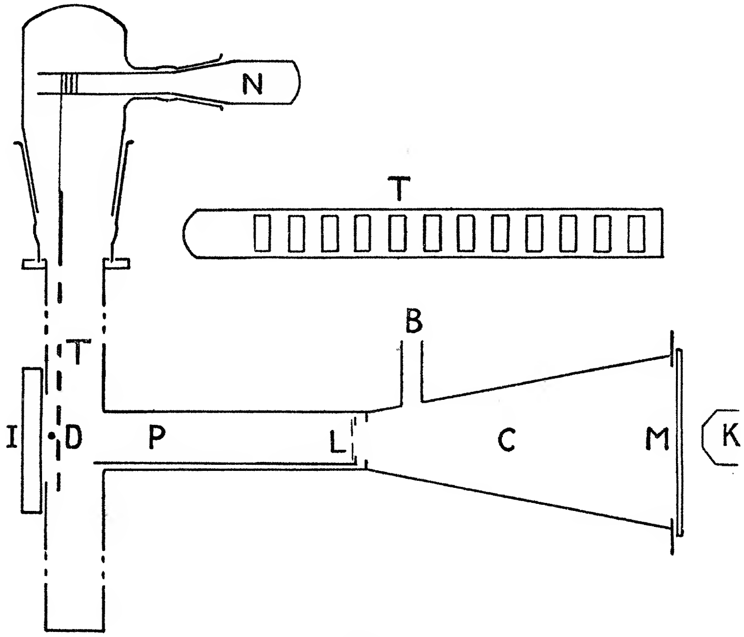


Fig. 1.

The source consisted of a fine platinum wire 1·5 cm. in length and 0·15 mm. in diameter which had been exposed to a strong source of radium emanation so as to become activated with a deposit of about 20 millicuries radium C. Twenty minutes after the wire was withdrawn from the emanation the radium A had practically disappeared, so that the $\alpha$-particles emitted came from radium C only. The source fitted with its ends in a support attached to the platform P, which also held the slit L, the wire being adjusted so as to be parallel to the slit and about 8 cm. from it. The platform could be slipped into the brass chamber and against a stop as shown in the figure, the opening being closed by a ground glass plate I, and the whole evacuated through a tube B by means of a Fleuss pump and cooled charcoal.

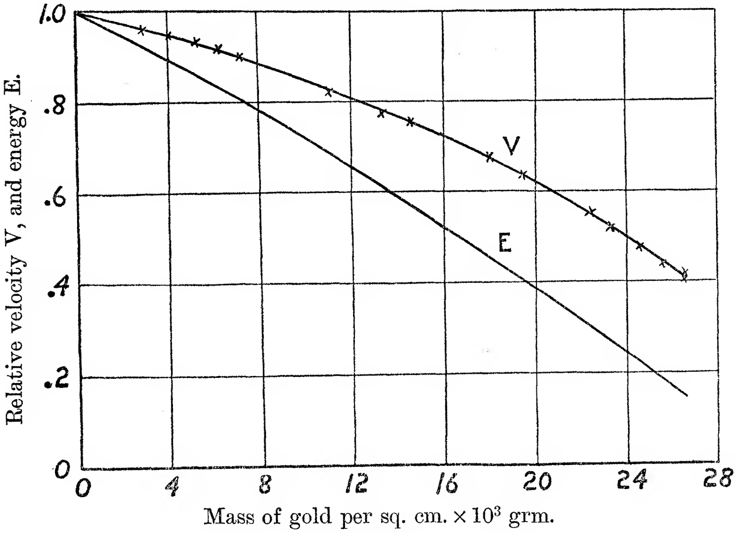
The foils whose absorption was under investigation were placed over windows in a "ladder" T, and by means of a piece of thread attached round a tube projecting from a ground-glass joint N any particular window could be placed opposite the source without altering the exhaustion in any way. The absorption foils were weighed in the form of single sheets and a number of layers taken, so that successive windows differed from one another by convenient amounts. In all cases the air equivalents of the windows were also obtained by the scintillation method, these measurements affording a useful check on the weighings.

The pencil of $\alpha$-particles passed through the slit and fell on the zinc sulphide screen, producing a fine line of scintillations, the position of which could be easily read to 1/20 mm. by means of a travelling microscope K. The magnetic field was then applied perpendicular to the plane of the diagram and the position of the line of scintillations again read. The successive windows were then moved in front of the source and the new positions of the line of scintillations determined. Similar observations were made with the same value of the magnetic field, but reversed, and the double deflections obtained by subtracting the corresponding readings. Measurements were continued with different field strengths up to 9000 gauss, until the radium C had decayed to such a small activity that observations were difficult to make. The relative velocities were calculated by substituting in the formula $mv/e = \mathrm{H}\rho$, where $m$, $v$, and $e$ are the respective values of the mass, velocity, and charge of the $\alpha$-particles, H the field strength and $\rho$ the radius of curvature of the path of the particles obtained from the relation $4\rho^2 d^2 = [b^2+d^2][d^2+(a+b)^2]$. In the latter formula $d$ is the deflection produced by the magnetic field as measured on the screen, and $a$ and $b$ the distances of the slit from the source and screen respectively. This formula applies to the experiments, as the whole of the path of the particles was in the magnetic field, which was uniform to less than 1 per cent. throughout the whole of its length. In all cases the ratios of the velocities, with and without absorption sheets, were calculated, and these are practically inversely proportional to the double deflections in the same magnetic field, a small correction being necessary, depending on the magnitudes of the deflections. An example of a set of readings is given in Table I.

The velocity curve obtained in the case of gold is shown in fig. 2, where the ordinates represent relative velocities and abscissæ the mass per unit area, or thickness × density, of the foils used. For foils greater than about 6 cm. air equivalent the velocity changes rapidly with thickness, and the method generally adopted was to place a foil of about 5·5 cm. air equivalent directly over the source, and to use additional foils for the windows of the "ladder" increasing in thickness by very small amounts.

Table I.—Gold Foils. Example of a set of readings.

| Exciting current of magnet. | Mass per unit area of "window." | Double deflection. | Relative velocity. |
|---|---|---|---|
| ampère. | grm. | cm. | |
| 1 | — | 0·635 | 1·0 |
| 1 | $9·63 \times 10^{-3}$ | 0·78 | 0·814 |
| 1 | 13·44 | 0·825 | 0·770 |
| 1 | 18·10 | 0·94 | 0·675 |
| 1 | 22·90 | 1·23 | 0·516 |
| 1 | 25·43 | 1·395 | 0·455 |
| 5 | — | 2·841 | 1·0 |
| 5 | $2·88 \times 10^{-3}$ | 2·96 | 0·962 |
| 5 | 4·31 | 3·032 | 0·940 |
| 5 | 6·25 | 3·12 | 0·915 |
| 5 | 9·63 | 3·515 | 0·817 |



Mass of gold per sq. cm. × 10³ grm.

Fig. 2.

The curve shown is seen to be smooth down to a velocity of 0·415 of the initial velocity corresponding to a mass per square centimetre of 0·0266 grm., or an air equivalent of 6·5 cm. at 15° C. and 76 cm. Hg. Here a somewhat unexpected difficulty was encountered, for with additional thickness of foil no further diminution in velocity could be detected. The line of scintillations apparently remained stationary although steadily decreasing in intensity with increasing thickness. Similar results were obtained with Cu, Al, and mica; in no case could we obtain with certainty a velocity less than about 0·415 of the initial velocity of expulsion. This question will be discussed more fully in a later section of the paper.

Table II gives the results of the experiments, the masses per unit area of the various materials being given which were necessary to cut down the velocity of the α-particles to the fractions given in column 1. The values are taken from smooth curves drawn through the experimental points. For gold and mica the values are probably correct to 1 per cent., although the results for copper and aluminium are not quite so reliable, owing to the unhomogeneity of the foils used. As the velocity changes comparatively slowly with the thickness, especially for thicknesses up to about 3 cm. air equivalent, the values of the velocity corresponding to any given thickness will have a considerably greater percentage accuracy. The foils were in all cases commercially pure. The values given for velocity 0·415 are taken from the curves as the smallest mass per square centimetre necessary to give this velocity. The values given in the last line of the table are the masses per square centimetre necessary to completely absorb the α-particles in the various materials. These numbers were not determined directly, but by extrapolation from the values necessary to cut down the range by about 6·5 cm. in air, using for the remainder of the range the numbers given by Richardson and one of us.* The method by which the values for air given in the last column were obtained is given in the next section.

Table II.

| Relative velocity. | Mass per unit area × $10^3$ grm. | | | | |
|---|---|---|---|---|---|
| | Gold. | Copper. | Aluminium. | Mica. | Air. |
| 1·0 | — | — | — | — | — |
| 0·95 | 4·00 | 2·08 | 1·48 | 1·43 | 1·24 |
| 0·90 | 7·05 | 3·90 | 2·79 | 2·75 | 2·32 |
| 0·85 | 9·79 | 5·35 | 3·94 | 3·83 | 3·26 |
| 0·80 | 12·27 | 6·69 | 5·01 | 4·86 | 4·08 |
| 0·75 | 14·80 | 8·00 | 6·05 | 5·72 | 4·84 |
| 0·70 | 17·04 | 9·20 | 7·03 | 6·40 | 5·46 |
| 0·65 | 18·99 | 10·30 | 7·85 | 7·00 | 6·02 |
| 0·60 | 20·71 | 11·40 | 8·50 | 7·50 | 6·48 |
| 0·55 | 22·29 | 12·35 | 9·10 | 7·98 | 6·90 |
| 0·50 | 23·89 | 13·13 | 9·64 | 8·47 | 7·29 |
| 0·45 | 25·40 | 14·00 | 10·15 | 8·96 | 7·67 |
| 0·415 | 26·65 | 14·60 | 10·46 | 9·35 | 7·96 |
| End | 29·50 | 16·00 | 11·40 | 10·15 | 8·50 |

In connection with the above experiments the value of *mv/e* for the unabsorbed α-particles was determined by substitution of the various values in the formulæ given above. The distances of the source from the slit and screen were 8·185 and 16·565 cm. respectively. With six values of the field varying between 4000 and 8500 gauss, the values of *mv/e* determined from the observed deflections were 4·00, 4·00, 3·99, 4·00, 4·00, 4·015 × $10^5$ electromagnetic units respectively, with a mean of 4·00 × $10^5$. The concordance of these results shows the sensitiveness of the method of measurement. The mean result is probably correct to ½ per cent., an uncertain error arising from the details of the ordinary laboratory instruments used in the calibration. An accurate investigation of initial velocity and $e/m$ is at present in progress by Prof. Rutherford and Mr. Robinson in this laboratory. In two experiments values were obtained of the relative velocity of the $\alpha$-particles from radium A by making the observations within a few minutes after withdrawing the source from the emanation. The mean value obtained was 0·882 of the velocity of the radium C $\alpha$-particles, and this value is in excellent agreement with the value deduced from the known ranges.*

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* Marsden and Richardson, 'Phil. Mag.,' 1913, vol. 25, p. 184.

### *Velocity Curve in Air.*

If a foil is taken of air equivalent $a$, and which reduces the velocity of an $\alpha$-particle to a fraction $\rho$, then $a, \rho$ is a point on the air velocity curve. Consequently, by plotting the air equivalents of the foils used in the above determinations against the velocities of the emergent $\alpha$-particles, the air velocity curve can be determined. The values obtained from the curves for gold and mica are given in Table III, where columns 2 and 3 give the air equivalents at 15° C. and 76 cm. Hg of the foils corresponding to the relative velocities given in column 1.

Table III.—Velocity Curve in Air, 15° C. and 76 cm. Hg.

| Velocity. | Air values as deduced from— | | Experimental air value. | Weighted mean. | Value deduced from formula $v^3 = aR$. |
|---|---|---|---|---|---|
| | Gold. | Mica. | | | |
| | cm. | cm. | cm. | cm. | cm. |
| 1·0 | — | — | — | — | — |
| 0·95 | 1·02 | 1·00 | 1·02 | 1·01 | 0·99 |
| 0·90 | 1·85 | 1·92 | 1·87 | 1·89 | 1·88 |
| 0·85 | 2·64 | 2·68 | 2·57 | 2·66 | 2·68 |
| 0·80 | 3·28 | 3·35 | 3·30 | 3·33 | 3·39 |
| 0·75 | 3·89 | 3·98 | 3·95 | 3·95 | 4·01 |
| 0·70 | 4·40 | 4·47 | 4·47 | 4·46 | 4·56 |
| 0·65 | 4·87 | 4·92 | 4·92 | 4·91 | 5·03 |
| 0·60 | 5·29 | 5·27 | 5·40 | 5·29 | 5·44 |
| 0·55 | 5·65 | 5·62 | 5·75 | 5·63 | 5·79 |
| 0·50 | 6·00 | 5·92 | 6·10 | 5·95 | 6·07 |
| 0·45 | 6·30 | 6·25 | 6·35 | 6·26 | 6·31 |
| 0·415 | 6·50 | 6·50 | 6·48 | 6·50 | 6·44 |
| End | 6·94 | 6·94 | 6·94 | 6·94 | 6·94 |

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* *Cf.* Geiger and Nuttall, 'Phil. Mag.,' October, 1912, vol. 24, p. 647.

It is assumed in using the above data that the α-particles are absorbed similarly by the various materials, *i.e.* either that the emergent α-particles are homogeneous in velocity or that they are "straggled" or sorted out in velocities to the same extent. This question has been discussed by Richardson and one of us (*loc. cit.*), and further evidence will be given in the next section of this paper. It appears to us that we are justified in obtaining the air velocity curve in this way, at any rate to an accuracy within the possible experimental error, especially for velocities above 0·5 of the initial velocity. A difficulty arises in measuring the air equivalents of foils greater than that corresponding to about 6·5 cm. If the experiment is done in air at ordinary pressure either by ionisation or by the scintillation method this difficulty is due to the large variation in intensity of the α-particles at the end of the range with the source uncovered (*i.e.* at about 7 cm. distance), and the end of the range when such a thick foil is interposed (*i.e.* less than 1 cm. distance). In our experiments the scintillation method was used, with radium C as source. A zinc sulphide screen was adjusted at the end of the range with and without the various foils interposed. For the very thick foils the source was sometimes allowed to decay to a small intensity before making the adjustment with the foil covering the source. The difference between the distances of the zinc sulphide screen from the source with and without the foil over it gives the air equivalent required. As a check on the values for the thicker foils the source, foils, and screen were enclosed in a chamber which could be evacuated. A constant distance separated the source and the screen, and the pressure was adjusted until the α-particles just failed to reach the screen. Even with these precautions a difficulty was encountered owing to the unhomogeneity of the foils, and for this reason more reliance is placed on the values obtained with mica.

The values are all reduced to 15° C. and 76 cm. Hg. The masses per unit area corresponding to any air equivalent are in general a few per cent. less than the values determined by Richardson and one of us from the variation of air equivalent along the range of foils of the order of 1 cm. air equivalent. For this reason the masses given by these authors for the equivalents per centimetre at various points of the range will require diminishing by a factor constant for each substance.

A direct determination of the air velocity curve was also made, although owing to the nature of the experiment the values obtained are probably not quite so accurate as those deduced by the above method. The apparatus of fig. 1 was used, the slide holding the source and slit being modified as shown in fig. 3. The plate P held a fine slit $S_1$ covered airtight by a thin mica window equivalent to about 0·9 cm. air, and the whole was waxed so as to cover the opening (I in fig. 1) also airtight. The source was placed at W at a definite distance from $S_1$, and a bell-jar fitted air-tight over $S_1$ and the plate P. The slide carried a second slit $S_2$ in line with $S_1$ and W.

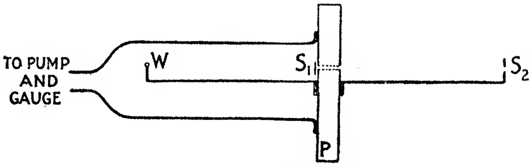

Fig. 3.

The main chamber was evacuated completely, and the pressure varied in the bell-jar. In this way the range of the $\alpha$-particles entering the magnetic deflecting chamber could be varied. The air equivalent of the mica window was known at different parts of the range, and by adding the equivalent at 15° and 76 cm. Hg. of the air between W and $S_1$ at the various pressures the exact reduction of range could be calculated. The reason that two slits were necessary arose from the considerable "compound" scattering of the beam of $\alpha$-particles, which would otherwise cause a spreading out of the pencil received on the zinc sulphide screen. Even with the above arrangement a certain amount of spreading of the beam due to scattering is unavoidable, and also for the same reason there is a considerable reduction in the intensity of the $\alpha$-particles for low velocities where the scattering becomes considerable. Thus measurements of a high degree of accuracy could not be obtained by this method. The results are given in Column 4 of Table III, and they prove the substantial accuracy of the values calculated by the former method. As in the experiments with metal foils no certain evidence could be obtained of velocities below 0·415 of the initial velocity.

### *Attempts to Obtain Velocities below* 0·41 *of the Initial Velocity.*

It has already been mentioned that with foils of any material, of thickness from 6·5 cm. air equivalent upwards, no reduction in velocity could be obtained below 0·415 of the initial velocity. This result is in agreement with Prof. Rutherford's original experiments (*loc. cit.*), in which a lower limit of 0·43 was obtained. Rutherford used aluminium foils and a photographic plate to register the deflected bands of $\alpha$-particles, and it has generally been assumed that his failure to obtain low velocities arose from the want of uniformity of his foils. Geiger (*loc. cit.*), using mica as absorbing substance and the scintillation method, obtained two values of velocity as low as 0·39 and 0·27 of the initial velocity respectively.

Observations at the end of the range are difficult owing to several causes: Firstly, there is a rapid decrease in the number of $\alpha$-particles which penetrate foils of air-equivalent greater than about 6·5 cm. This decrease arises from the phenomena of compound scattering, for the most probable angle of scattering* for sheets of gold and mica of 6·5 cm. air-equivalent are of the order 20° and 5° respectively, and the scattering will then increase very rapidly with increasing air equivalent. Consequently, only a fraction of the $\alpha$-particles will emerge from such foils, due to the increased distance traversed in an oblique direction through them, and it would also be expected that there would be a variation in velocity in the $\alpha$-particles which do emerge. Further, not only is the number of $\alpha$-particles in the beam greatly reduced, but the brightness of the scintillations themselves decreases considerably, and observation becomes difficult.

From these considerations it will be seen that for low velocities it is necessary to use a very intense source, and to place uniform absorption sheets directly over it so as to keep the spreading of the beam at a minimum. However, with these precautions, and using the arrangement of sliding absorption windows, we were unable, as has already been stated, to obtain velocities below 0·415 of the initial velocity. In all cases the deflection caused by a magnetic field remained constant for foils greater than 6·5 cm. air equivalent. An experiment was tried in which the increase of thickness was obtained by rotating a sheet of mica of about 6 cm. air-equivalent about an axis parallel and very near to the source. The same result was obtained; after a certain rotation the deflected beam remained stationary until it was too faint to observe. This result was obtained whether the whole of the apparatus was in the magnetic field or only that part from the slit to the zinc sulphide screen.

In another experiment the apparatus was cut down to half its length, and a source of radium C equivalent to the amount in equilibrium with 15 millicuries of radium emanation was used, on a wire of 1/10 mm. diameter, with a slit 1/10 mm. wide. Three foils of mica, equivalent to 6·5, 6·6, and 6·8 cm. of air, were employed successively and placed directly over the source with a separate evacuation for each experiment. The resultant double deflections were 3·35, 3·33 and 3·25 mm. respectively, and the double deflection for the bare wire was 1·40 mm. These values are constant within the limits of experimental error due to the extreme faintness of the bands, the mean value of the velocity being 0·42 of the velocity with the source uncovered. The cross wire in the microscope was set in each case on the centre of the band of scintillations.

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* H. Geiger, 'Roy. Soc. Proc.,' 1910, A, vol. 83, p. 492.

Owing to the faintness of the bands there was some difficulty in estimating any possible unhomogeneity in velocity. However, the deflected band appeared narrower for the greater thicknesses. For the mica equivalent to 6·5 cm. the measurements indicated that $\alpha$-particles of 39 to 47 per cent. of the initial velocity were present. However, a lower limit of velocity was not at all evident even with the thicker micas.

### *Discussion of Results.*

It will be more convenient first to discuss the results of the last section. It is possible that in the beam of $\alpha$-particles after passing through 6·5 cm. air-equivalent, the velocities are distributed within the limits 39 to 47 per cent., just mentioned. With further absorption the particles of higher velocities may become degraded in velocity. However, we are faced with the difficulty of accounting for the absence of $\alpha$-particles of lower velocities. It is possible that they no longer produce scintillations. This point was investigated with different zinc sulphide screens but with negative results. But even if they no longer produce scintillations then it is probable that they also no longer ionise, for the ranges of $\alpha$-particles determined by the scintillation method are the same as those determined by the ionisation method.

The results may possibly be explained by assuming that when the velocity of an $\alpha$-particle falls below a certain value it is subject to a new special type of scattering, possibly by some kind of sub-central charge present in the atom. From an examination of the large number of $\alpha$-particles in the photographs of C. T. R. Wilson* which exhibit large angle deflections in the last 2 mm. of the range as shown by the cloud trails we have calculated that this number is far in excess of the number to be expected on the laws of single scattering of Rutherford,† experimentally proved by Geiger‡ and one of us. However, with such an hypothesis one might expect some difference in the limiting velocity with different substances unless it is supposed that the same sub-centres are present in all atoms.

An alternative explanation may, of course, be obtained on the assumption that at this particular velocity the $\alpha$-particle takes on an electron and then has only one positive charge. This would account for the limiting velocity coming practically the same in all the substances. An attempt was made to detect such singly charged $\alpha$-particles but only one line of scintillations in the magnetically deflected beam could be observed.

It must be remembered, however, that Geiger apparently obtained one value of the velocity as low as 0·27. We tried to repeat his conditions but were unable to obtain such a low velocity. Whether Geiger's result may prove correct or not there must be some very radical change accompanying the absorption of the α-particles when their velocity falls to 0·41 of the initial velocity (radium C).

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* C. T. R. Wilson, 'Roy. Soc. Proc.,' 1912, A, vol. 87, p. 277.

† E. Rutherford, 'Phil. Mag.,' 1911, vol. 21, p. 669.

‡ H. Geiger and E. Marsden, 'Phil. Mag.,' 1913, vol. 25, p. 604.

We now turn to the discussion of the figures given in the first section of the paper for the velocity curves in the various materials. For the air-velocity curve Geiger deduced from his results the formula $V^3 = aR$, where V is the velocity, $a$ a constant and R the range of the α-particles emerging from the absorbing foil. Putting in the value 6·94 for the total range at 15° and 76 cm. Hg, the values given in Column 6 of Table II were deduced and it will be seen that except for velocities less than 0·41 they show a good agreement with the experimental values. With regard to the velocity curves in other materials the formula does not hold, the curve approaching more nearly to that expressed by $V^2 = aR$ for substances of increasing atomic weight. This is indicated by the energy curve for gold shown in fig. 1.

Darwin (*loc. cit.*) first attempted to deduce expressions for the velocity curve in various materials, the assumption being that the α-particle loses energy by setting in motion the electrons in the atoms of the absorbing substance. To avoid, as far as possible, any hypotheses as to the structure of atoms Darwin also assumed that an α-particle only acts on the electrons in an atom when it actually passes through the atom. Bohr has extended Darwin's results and removed the objection of limiting the action of the α-particle. Bohr arrives at a formula which may be reduced to

$$\frac{dV}{dx} = -\frac{A}{v^3}\left\{\frac{B}{A}\log V + 1\right\}^{*},$$

where $v$ is the velocity of an electrified particle, $x$ the distance traversed through the absorbing material and A and B are constants. We have applied this formula to our results, but the agreement is only good for velocities greater than about 0·6 of the initial velocity. This, however, does not altogether contradict the theory, for certain assumptions used by Bohr in integrating his formula do not hold for low velocities. For instance, the formula depends on the assumption that a certain distance $\lambda\,[= eE(M+m)/V^2 mM]$ exists, which is very small in comparison with

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* Bohr's actual formula is $\frac{dV}{dx} = -\frac{4\pi e^2 E^2 N}{mMV^3}\sum_{s=1}^{s=r}\log\left(\frac{V^3 kMm}{n_s eE(M+m)}\right)$. E and M are the charge and mass of the electrified particle, $e$ and $m$ the corresponding quantities for an electron. N is the number of atoms per unit volume, and $k$ a constant = 1·123. The frequencies of the $r$ electrons in each atom are denoted by $n_1, n_2, \ldots n_r$.

$V/n$. This assumption comes in in the consideration of the effect of the atomic forces on the motion of the electrons disturbed by an $\alpha$-particle.

If we consider the variation in the velocity of an $\alpha$-particle when $V/V_0 = 0{\cdot}5$, say, *i.e.* $V = 1{\cdot}0 \times 10^9$, it can be calculated that $n$ must be extremely small compared with $2{\cdot}0 \times 10^{18}$ for this assumption to hold. For oxygen, Bohr calculates from data of Planck and of Whiddington that for some electrons in the atom $n = 1{\cdot}1 \times 10^{18}$, and that for materials of higher atomic weight electrons of much higher frequencies must exist. Thus Bohr's conditions probably do not hold for low velocities, and this possibility he has himself already pointed out.

It is interesting to note that no theoretical explanation has so far been given for Bragg's law that the absorption of $\alpha$-particles per atom of different substances is proportional to the square root of the atomic weight. This law is not strictly accurate, as it cannot hold for all velocities of $\alpha$-particles, yet its wide range of approximate application seems to suggest that it has some simple theoretical foundation.

We are deeply indebted to Prof. Rutherford for his helpful encouraging interest in these experiments, and for supplying us with the large quantities of radium emanation necessary.